

POWER MANAGEMENT TOPOLOGIES

CROSS REFERENCE TO RELATED APPLICATIONS

5 This application is a continuation-in-part application of US Nonprovisional
Application Ser. No. 10/652,110 filed August 29, 2003, which itself is a continuation-in-
part application of US Nonprovisional Application Ser. No. 10/364,228 filed February
11, 2003, the teachings of which are incorporated herein by reference, and claims the
benefit of the filing date of U.S. Provisional Application Ser. No. 60/484,635, filed July
10 3, 2003, the teachings of which are also incorporated herein by reference. US
Nonprovisional Application Ser. No. 10/652,110 filed August 29, 2003 is also a
continuation-in-part of US Nonprovisional Application Ser. No. 09/960,453 filed
September 21, 2001, the teachings of which are incorporated herein by reference, and
claims the benefit of the filing date of U.S. Provisional Application Ser. No. 60/234,442,
15 filed September 21, 2000, the teachings of which are also incorporated herein by
reference

FIELD OF THE INVENTION

 The present invention relates to power management systems, and in particular to
20 various power management topologies for electronic devices.

BACKGROUND OF THE INVENTION

Various portable electronic devices have a power supply system that monitors, controls, and directs power from various power sources to supply power to the system load of the electronic device. These power sources generally include a fixed output ACDC adapter and one or more rechargeable batteries. The power supply system
5 contains a power conversion block, e.g., a DC to DC converter to convert a fixed DC voltage supplied by the ACDC adapter to a finely controlled variable output DC voltage to charge the battery.

The power supply system operates to supply power to the system from either the ACDC adapter or from the host battery and to perform battery charging if proper
10 conditions are met. As such, there is typically an ACDC source switch for selectively coupling the ACDC adapter to the system, a Battery switch for selectively coupling the host battery to the system, and a charging switch that may connect the host battery to an output of the DC to DC converter for charging. When power is supplied to the system from the ACDC adapter, the ACDC source switch is closed, the Battery switch is
15 open, and the charging switch may either be open or closed. In contrast, when power is supplied to the system from the battery, the Battery switch is closed, the ACDC source switch and the charging switch are open.

In order to be able to charge the battery up to its maximum operating voltage, the output voltage of the ACDC adapter is chosen to be higher (usually at least 1 to 2 V
20 higher) than the maximum operating voltage of the battery. Since the output voltage of the ACDC adapter has a fixed value while the output voltage of the battery may vary largely (depending on its charged state) the ACDC adapter and the battery can not be

coupled in parallel to supply power to the system load at certain times. This difference in voltage would lead to undesirable inter-current flow from the higher voltage source (ACDC adapter) to the lower voltage source (battery). As a result, in order to account for transient high power needs of the system, the ACDC adapter is typically oversized, significantly increasing the cost of the power supply system.

In addition, since the ACDC adapter's output voltage is fixed, its output voltage cannot be used to charge the battery which entails fine charging voltage and current control. As such, a second power conversion step accomplished by the DC to DC converter is compulsory. This second power conversion step causes further cost increase and diminishes the overall efficiency of the power supply system.

Accordingly, there is a need in the art for power management topologies that enables only one power conversion to provide a controllable DC output to the system load and the battery, or enables a controllable DC power source and battery to be coupled in parallel to supply the system load, or has both features.

BRIEF DESCRIPTION OF THE DRAWINGS

Advantages of the present invention will be apparent from the following detailed description of exemplary embodiments thereof, which description should be considered in conjunction with the accompanying drawings, in which:

FIG. 1 is a high-level block diagram of an electronic device having a power supply topology including a controllable DC power source and a power management control circuit consistent with the invention;

FIG. 2 is a high-level block diagram of one embodiment of a power supply topology of an electronic device consistent with FIG. 1 where the controllable DC power source is a controllable adapter;

FIG. 3 is a high-level block diagram of another embodiment of a power supply topology of an electronic device consistent with FIG. 1 where the controllable DC power source is a DC to DC converter that may accept power from a fixed output adapter;

FIG. 4 is a more detailed block diagram of one embodiment of the power supply topology of FIG. 2 where the controllable DC power source is a controllable adapter, the battery source includes a plurality of batteries, and the power supply system includes an adapter sense resistor, a system sense resistor, and a sense resistor for each battery;

FIG. 5 is a more detailed block diagram of another embodiment of the power supply topology of FIG. 2 where the controllable DC power source is a controllable adapter, the battery source includes a plurality of batteries, and the power supply system includes an adapter sense resistor and a sense resistor for each battery;

FIG. 6 is a more detailed block diagram of yet another embodiment of the power supply topology of FIG. 2 where the controllable DC power source is a controllable adapter, the battery source includes a plurality of batteries, and the power supply system includes a system sense resistor and a sense resistor for each battery;

FIG. 7 is a more detailed block diagram of yet another embodiment of the power supply topology of FIG. 2 where the controllable DC power source is a controllable adapter, the battery source includes a plurality of batteries, and the power supply

system includes an adapter sense resistor and one battery sense resistor for the battery source;

FIG. 8 is a more detailed block diagram of yet another embodiment of the power supply topology of FIG. 2 where the controllable DC power source is a controllable adapter, the battery source includes a plurality of batteries, and the power supply system includes a system sense resistor at the output of the DC to DC converter, and one battery sense resistor for a plurality of batteries;

FIG. 9 is a more detailed block diagram of yet another embodiment of the power supply topology of FIG. 3 where the controllable DC power source is a DC to DC converter, the battery source includes a plurality of batteries, and the power supply system includes a DC to DC converter sense resistor at the output of the DC to DC converter, a system sense resistor, and one battery sense resistor for each battery;

FIG. 10 is a more detailed block diagram of yet another embodiment of the power supply topology of FIG. 3 where the controllable DC power source is a DC to DC converter, the battery source includes a plurality of batteries, and the power supply system includes a DC to DC converter sense resistor at the output of the DC to DC converter and a sense resistor for each battery;

FIG. 11 is a more detailed block diagram of yet another embodiment of the power supply topology of FIG. 3 where the controllable DC power source is a DC to DC converter, the battery source includes a plurality of batteries, and the power supply system includes an system sense resistor and a sense resistor for each battery;

FIG. 12 is a more detailed block diagram of yet another embodiment of the power supply topology of FIG. 3 where the controllable DC power source is a DC to DC converter, the battery source includes a plurality of batteries, and the power supply system includes an adapter sense resistor and one battery sense resistor for the battery source;

FIG. 13 is a more detailed block diagram of yet another embodiment of the power supply topology of FIG. 3 where the controllable DC power source is a DC to DC converter, the battery source includes a plurality of batteries, and the power supply system includes a system sense resistor and one battery sense resistor for the battery source;

FIG. 14 is a more detailed block diagram of yet another embodiment of the power supply topology of FIG. 3 where the controllable DC power source is a DC to DC converter, the battery source includes a plurality of batteries, and the power supply system includes a DC to DC converter sense resistor at the output of the DC to DC converter and one battery sense resistor for the battery source;

FIG. 15 is a more detailed block diagram of yet another embodiment of the power supply topology of FIG. 3 where the controllable DC power source is a DC to DC converter, the battery source includes a plurality of batteries, and the power supply system includes an adapter sense resistor at the output of the fixed adapter and a sense resistor for each battery;

FIG. 16 is a block diagram of another embodiment of an electronic device having a wake up circuit to control charging current to a deeply discharged battery; and

FIG. 17 is a more detailed block diagram of the power management and wake up circuit of FIG. 16.

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DETAILED DESCRIPTION

FIG. 1 illustrates a simplified block diagram of an electronic device 100 having a system load 110 capable of being powered by a controllable DC power source 104, a battery 105, or by both in parallel as the need arises as further detailed herein. A table 10 180 showing the position of switches SW1 and SW2 in various power supply modes is also illustrated. In one embodiment, the controllable DC power source 104 may be a controllable adapter as further detailed herein, e.g., an ACDC adapter, that provides the only power conversion necessary to deliver power to the system load 110 and the battery 105. As such, the need for an additional power conversion step (e.g., a DC to 15 DC converter to provide a finely controlled output to the battery for charging) typically utilized in other power supply systems is obviated in this instance.

The electronic device 100 may be any variety of devices known in the art such as a laptop computer, cell phone, personal digital assistant, power tool, electric powered vehicle, etc. The controllable DC power source 104 provides a dynamically controllable 20 DC output such as may be available from a controllable adapter or a DC to DC converter as further detailed herein with reference to various embodiments. The

controllable DC power source 104 may be separate from or integral with the electronic device 100. The battery 105 may include one battery or a plurality of batteries. A battery may be a rechargeable battery of various types such as lithium-ion, nickel-cadmium, nickel-metal hydride batteries, or the like.

5 The controllable DC power source 104 may be selectively coupled to a node 116 via switch SW1 and path 114. The battery 105 may be selectively coupled to the node 116 via switch SW2 and path 118. The system load 110 may be further coupled to the node 116 via path 121.

 In general, a power management control circuit 130 consistent with the invention
10 monitors, controls, and directs power from each power source 104, 105 to the system load 110 and each other (e.g., battery charging) under various conditions. The power management control circuit 130 may receive a variety of input signals along path 141. Such input signals may detail various load conditions, supply conditions, and/or command signals. The supply condition of the battery 105 may be a power condition
15 such as an output voltage level or an output current level of the battery 105. Similarly, the supply condition of the controllable DC power source 104 may be a power condition such as an output voltage level or an output current level of the source 104. The load condition of the system load 110 may be a power condition such as a required voltage level or required current level of the system load at any particular instant. Those skilled
20 in the art will recognize a variety of ways to provide such input signals to the power management control circuit 130. For instance, a current sense resistor may be provided

in series with respective power paths 114, 118, 121 to provide a signal representative of a current level along each respective path.

In general, the power management control circuit 130 may dynamically adjust an output parameter, e.g., an output voltage level, of the controllable DC power source 104 via an output control signal along path 133 and may select among a plurality of power supply modes by controlling the state of switches SW1 and SW2 via an output control signal along path 20.

Advantageously, in one embodiment, the power management control circuit 130 may select a power supply mode 185 as detailed in table 180 that enables both the controllable DC power source 104 and the battery 105 to be coupled in parallel to provide power to the system load 110. The problem in coupling the controllable DC power source 104 and the battery 105 in parallel is that a difference in voltage level between the two leads to an undesirable inter-current flow from the higher voltage source to the lower voltage source.

This undesirable inter-current flow can be prevented by unidirectional and selectively unidirectional switches to allow current flow in one direction but prevent it in another direction. For instance, switch SW2 may be a selectively unidirectional switch and switch SW1 may be a unidirectional switch as further detailed herein and indicated by the arrows in table 180 of permitted current flow in the buffer battery supply mode 185. In addition, switch SW2 may include a bidirectional discharge switch where undesirable inter-current flow between the controllable DC power source 104 and the battery 105 is controlled by maintaining the voltage level of the controllable DC

power source 104 within a tolerance range of the voltage level of the battery 105 as the battery voltage changes, e.g., depending on its charging status.

This parallel supply mode 185 may be selected if instructed by a command signal received via path 141. This supply mode 185 may also be selected in response to a power crises condition. Such a power crises condition may occur when the system load 110 has a load requirement in excess of the maximum power available from the controllable DC power source 104 individually and in excess of the maximum power available from the battery 105 individually. Together however, the power sources may be able to provide enough power to satisfy the load requirement of the system load 110 for the necessary duration. Therefore, the controllable DC power source 104 may not need to be oversized to account for this situation.

In such a parallel power source supply mode 185, the power management control circuit 130 advantageously prevents cross conduction between the controllable DC power source 104 and the battery source 105 by controlling the states of switches SW1 and SW2. Switch SW2 may be a selectively unidirectional switch and switch SW1 may be a unidirectional switch. That is, switch SW2 may allow current flow in one direction only when closed depending on the selected power supply mode or switch SW2 may be open. Switch SW2 may be open when the system load 110 is being powered by the controllable DC power source 104 only (hence switch SW1 is closed) and no charging is taking place (power supply mode 181).

Switch SW2 may have a first discharging closed position in which current is generally only allowed to flow from the battery. For example, in this first discharging

closed position current is allowed to flow from the battery 105 to the system load 110 but current is prevented from flowing towards the battery 105 from the controllable DC power source 104. In addition, switch SW2 may also have a second charging closed position in which current is only allowed to flow to the battery. For example, in this
5 second charging closed position current is only allowed to flow to the battery 105 from the controllable DC power source 104 and prevented from flowing from the battery 105 to the system load 100. Switch SW1 may be a unidirectional switch that when closed only allows current flow from the controllable DC power source 104 to node 116.

Hence in a parallel power supply mode 185 where both the controllable DC
10 power source 104 and the battery 105 provide power to the system load 110, switch SW2 may be closed in the first discharging position and switch SW1 may be closed. Hence the battery 105 can supply current to the system load 110 but undesirable inter-current flow from the controllable DC power source 104 to the battery 105 is prevented by the switch SW2. In addition, undesirable inter-current flow from the battery 105 to
15 the DC power source 104 is prevented by unidirectional switch SW1.

Those skilled in the art will recognize a variety of ways a selectively unidirectional switch may be implemented. For instance, a pair of switches coupled in series with each other, and an associated pair of diodes in parallel with each switch, may be utilized. A particular diode may block current flow in one direction while a
20 closed switch may allow current flow in both directions.

Advantageously, the power management control circuit 130 may select another power supply mode 181 or 183 where the controllable DC power source 104 provides

power to the system load 110. The battery 105 may be charged (supply mode 183 of table 180) or may not be charged (supply mode 181 of table 180) in such an instance. In these power supply modes, one of the input signals to the power management circuit 130 along path 114 may be representative of a power requirement of the system load 110, e.g., a voltage requirement, a current requirement, etc. Advantageously, the power management control circuit 130 may be responsive to such a signal to adjust an output parameter, e.g., output voltage level, output current level, etc., of the controllable DC power source 104 to follow the requirement of the system load 110. In one instance, the power management circuit 130 adjusts the output voltage level of the controllable DC power source 104 to be within a predetermined limit of the voltage requirement of the system load 110. As such, power losses and dissipation are limited.

Turning to FIG. 2, the controllable DC power source 104 of FIG. 1 may be a controllable adapter 104a. Advantageously in this instance there is only one power conversion step (e.g., from the input voltage to the controller adapter to the controllable output DC voltage) necessary to supply power to the system load 110 and to the battery 105 for charging. As such, the added power conversion step (e.g., from a DC to DC converter to the battery for charging) is avoided improving power efficiency. In the embodiment of FIG. 2, the buffer battery supply mode previously detailed may be (table 180) or may not be (table 190) available depending on the needs of the desired power supply system.

Other than the controllable adapter 104a other components of the power supply system of FIG. 2 are similar to that of FIG. 1 and, as such, are labeled similarly. Hence,

any repetitive description of such components is omitted herein for clarity. The controllable adapter 104a may further be a controllable ACDC adapter that receives conventional AC voltage and converts it to a controllable DC voltage level in response to a control signal along path 133 from the power management control circuit 130. The parameters of the controllable adapter 104a that may be controlled by the power management control circuit 130 include, but are not limited to, output voltage, maximum output power, maximum output current, start-up time, start-up profile, etc. The output voltage of the controller adapter 104a may be dynamically adjusted as controlled by the power management control circuit 130.

Turning to FIG. 3, the controllable DC power source of FIG. 1 may be a DC to DC converter 104b coupled to path 114. Also coupled to path 114 is a switch SW1 and fixed adapter 302. Switch SW1 is illustrated as coupled to path 114 between the DC to DC converter 104b and the node 116. Alternatively, switch SW1 may be coupled between the fixed adapter 302 and the DC to DC converter 104b along path 114 as is further detailed in other embodiments of FIGs. 9 through 15.

In the embodiment of FIG. 3, two power conversions are made rather than one power conversion as illustrated in FIG. 2. That is, the power conversion of the fixed adapter 302 and the DC to DC converter 104b. The embodiment of FIG. 3 still enables the power supply system to be operated in a buffer battery supply mode 185, e.g., to have the battery 105 and the controllable DC power source 104b provide power to the system load 110 concurrently as previously detailed. Other than the DC to DC converter 104b and fixed adapter 302, other components of the power supply system of

FIG. 3 are similar to that of FIG. 1 and, as such, are labeled similarly. Hence, any repetitive description of such components is omitted herein for clarity.

The DC to DC converter 104b may be any variety of converters controlled by any variety of control signals along path 303 from the power management control circuit

5 130. In one embodiment, the DC to DC converter 104b may be a buck converter having a high side switch, a low side switch, and an LC filter as is known in the art. The control signal from the power management circuit 130 may be a pulse width modulated (PWM) signal. The width of the PWM signal controls the duration of the "switch ON" state (high side switch ON and low side switch OFF) and "switch OFF" state (high side
10 switch OFF and low side switch ON) and hence the output voltage and current level of the DC to DC converter 104b.

Turning to FIGs. 4 through 8, various embodiments of power supply systems consistent with the invention are illustrated having a controllable adapter 104a as the controllable DC power source 104 and two batteries (Battery A and B). As such, the
15 embodiments of FIGs. 4 through 8 have one power conversion due to the controllable adapter 104a to supply power to the system load 110 and the battery 105. The one step power conversion embodiments may be used independently of, or together with, the earlier detailed buffer battery power supply mode enabling both the battery and controllable DC power source to provide power to the system load 110.

20 In contrast, FIGs. 9 through 15 as further detailed herein are directed to additional embodiments having a controllable DC to DC converter 104b as the controllable DC power source 104 and also having two batteries (Batteries A and B).

The embodiments of FIGs. 9 through 15 therefore have at least two power conversions due to a fixed adapter 302 and the DC to DC converter 104b.

The embodiment of FIG. 4 may have all the functionality earlier detailed regarding FIG. 1 and FIG. 2. However, the embodiment of FIG. 4 may or may not have the earlier detailed buffer battery power supply mode enabling both the battery and controllable DC power source to provide power in parallel to the system load 110. For instance, a particular power supply system may only desire the one step power conversion and not be concerned with the buffer battery power supply mode.

Some components of FIG. 4 are similar to those components of FIG. 2 and, as such, are labeled similarly. Hence, any repetitive description of the functionality and the repetitive components is omitted herein for clarity. In general, any one or combination of the controllable ACDC adapter 104a, Battery A, or Battery B may power the system load 110 at any one time as controlled by the power management control circuit 130. The system load 110 receives power via path 121 as seen at node 116. The controllable adapter 104a may be selectively coupled to node 116 via switch SW1 and path 114. Battery A may be selectively coupled to node 116 via switch SW2A and path 118a. Similarly, Battery B may be selectively coupled to node 116 via switch SW2B and path 118b. Switch SW1 may be a stand-alone external switch. Switch SW1 may also be a unidirectional switch as earlier detailed. Switches SW2A and SW2B could be stand-alone switches or embedded in battery packs 10a and 11a respectively, e.g., extended battery life approach. Using the power switches embedded in the battery pack would

reduce the number of power switches and associated power dissipation. Switches SW2A and SW2B may also be selectively unidirectional switches as earlier detailed.

As earlier alluded, the power management control circuit 130 may receive a variety of input signals along a variety of paths. In the embodiment of FIG. 4, an adapter sense resistor 4, a system sense resistor 3, a Battery A sense resistor 7, and a Battery B sense resistor 5 provide input signals representative of the current level along the respective power paths to the power management control circuit 130. For instance, the adapter sense resistor 4 provides a data signal representative of current flow along path 114 from the controllable adapter 104a. The system sense resistor 3 provides a data signal representative of current flow along path 121 to the system load 110 from any combination of power sources. The Battery A sense resistor 7 provides a data signal representative of current flow along path 118a from or to Battery A. Finally, the Battery B sense resistor 5 provides a data signal representative of current flow along path 118b from or to Battery B.

In addition, input signals representative of the voltage level of Battery A (VFB_A), Battery B (VFB_B), and the system load (VFB_SYS) may also be input to the power management control circuit 130. Furthermore, input signals, e.g., command and data signals may also be input to the power management circuit 130 from a host power management unit (PMU) 12 via host bus 22. The PMU 12 is configured to run various power management routines as is known in the art. Such input signals from the PMU 12 may include, but are not limited to, charging current, charging voltage, adapter controlled preset voltage, adapter power limit, adapter current limit, adapter presence,

battery presence, a number of alarm signals such as over-voltage, over-temperature, over current charge or adapter, over-power for the adapter 104a or the system 110. The host bus 22 may have any number of wires and carry any combination of analog and digital command signals. For example, the host bus 22 may be a SMBus if the PMU 12 is configured to run a SMBus protocol routine. The PMU 12 may be a separate component or it may be embedded in a more complex processor of the electronic device 100.

In addition, a battery bus 24 for Batteries A and B may provide additional information to the power management control circuit 130. Such information provided via such bus 24 may be representative of various parameters such as, but not limited to, charging current, charging voltage, battery presence, a number of alarm signals such as over-voltage, over-temperature, or over current.

Turning to the power management control circuit 130, it may include a host interface 13, a plurality of current sense amplifiers 14, 15, 17, 18, associated control and data paths, and a decision circuit 16. The decision circuit 16 may further include a selector circuit 409 to provide a first set of output signals via bus 20 to control the state of switches SW1, SW2A, and SW2B. The decision circuit 16 may also include a control circuit 411 to provide a second set of output signals via path 133 to control an output parameter of the controllable adapter 104a.

The host interface 13 is a generic interface configured to accept an input set of signals from the PMU 12 and to output a converted set of signals to the decision circuit 16 via internal signal bus 23. Such signals provided to the decision circuit 16 may

contain voltage and current limits for Battery A, Battery B, the controllable adapter 104a, and the system load 110. The host interface 13 may accept analog or digital signals from the PMU 12.

If the PMU 12 provides digital signals, the host interface may be any variety of digital interfaces such as an SMBus or I2C interface. In this instance, a multiplexer (MUX) and digital to analog converter (DAC) may also be provided in the interface 13 to convert digital to analog signals and to provide the appropriate number of analog signals to the decision circuit 16. The MUX may have any number channels depending, in part, on the number of signals provided to the decision circuit 16.

The plurality of current sense amplifier 14, 15, 17, 18 amplifies signals from the respective sense resistors 3, 4, 5, 7 since the sense resistor is typically quite small. For instance, sense amplifier 14 amplifies the voltage drop across the system sense resistor 3 and provides an ISYS signal representative of the current flow along path 121. Sense amplifier 15 amplifies the voltage drop across the adapter sense resistor 4 and provides an IAD signal representative of the current flow along path 114. Sense amplifier 17 amplifies the voltage drop across the Battery B sense resistor 5 and provides an ICDB signal representative of current flow along path 118b. Finally, sense amplifier 18 amplifies the voltage drop across the Battery A sense resistor 7 and provides an ICDA signal representative of current flow along path 118a.

The ISYS, IAD, ICDB, and ICDA signals from the respective sense amplifiers 14, 15, 17, 18 may then be provided to the decision circuit 16, and in particular, to the control circuit 411 portion of the decision circuit 16. In addition, the VFB_SYS signal

representative of the voltage level of the system load 110, the VFB_B signal representative of the voltage level of Battery B, and the VFB_A signal representative of the voltage level of Battery A may also be provided to the decision circuit 16, and in particular, to the control circuit 411 portion of the decision circuit 16.

5 The control circuit 411 accepts these input signals ISYS, IAD, ICDB, ICDA, VFB_SYS, VFB_B, and VFB_A and compares such signals to various threshold levels, e.g., as provided by the PMU 12. Based on such comparisons, the control circuit 411 provides the first set of output signals to control an output parameter, e.g., an output voltage level, of the adapter 104a via the adapter control bus 133.

10 The first set of output signals controls one or more output parameters of the controllable adapter 104a so that the power supply system performs a variety of tasks including those earlier detailed regarding FIGs. 1 and 2. In addition, such tasks may also include at least one of, but not limited to, the following:

- providing all the necessary adapter current up to a maximum output
15 current level of the adapter or up to the power supply limits of the system load 110, and if requested to provide charging current to charge the battery source 105;
- Limiting the total charging current delivered to the battery 105 during a
 charging mode to the difference between the maximum output current
20 level of the adapter 104a and the required current of the system load 110;

- providing the maximum charging current to each battery (Battery A and B) as long as the maximum charging voltage level has not been reached for any of the batteries;
- providing up to the maximum charging current to the lowest voltage battery as long as the maximum charging voltage has not been reached for any of the batteries; and
- providing a set maximum supply voltage to the system load 110 when no battery is present or no charge request is received.

Those skilled in the art will recognize various ways that such functionality of the control circuit 411 portion of the decision circuit 16 may be accomplished through hardware only, software only, or some combination thereof. For instance, with hardware the control circuit 411 may include a plurality of error amplifiers to compare signals ISYS, IAD, ICDB, ICDA, VFB_SYS, VFB_B, and VFB_A with an associated maximum threshold level for each monitored parameter. The plurality of error amplifiers may be configured as an analog “wired-OR” topology such that the error amplifier that first detects a condition exceeding the associated maximum level controls the command signal to the controllable adapter 104a. An appropriate output signal may then be sent to the controllable adapter 104a, e.g., to lessen an output power parameter of the adapter 104a if a maximum threshold limit is reached.

The second set of output signals provided by the decision circuit 16 via the selector output bus 20 controls the state of switches SW1, SW2A, and SW2B to enable the power supply system to have various power supply modes. Such second set of

output signals may be provided by the selector circuit 409 of the decision circuit 16. As a result, various power paths connecting the power sources (adapter 104a, Battery A, and Battery B) to the system load 110 and to each other (e.g., during charging) occur depending on actual supply conditions, events, and requests from the PMU 12. A

5 variety of hardware and/or software may be utilized to process the variety of input signals to the selector circuit 409 portion of the decision circuit 16 according to a particular processing algorithm. The algorithm should be able to determine the appropriate driving signals to drives switches SW1, SW2A, and SW2B ON and OFF in order to accomplish a variety of tasks including at least one of, but not limited to, the
10 following tasks:

- ensuring an uninterrupted power supply to the system load 110 as long as at least one power source (ACDC adapter 104a, Battery A, Battery B) is present;
- connecting the appropriate battery or batteries to a charging path as
15 requested by the PMU 12;
- connecting the appropriate battery or batteries to a discharging path to supply power to the system load 110 as requested by the PMU 12;
- avoiding cross conduction between batteries when a number of batteries are coupled in parallel and between the ACDC adapter and the batteries
20 in parallel supply mode;
- independently solving any power crises event such as power source connection/disconnection, short circuits, and the like; and

- independently and safely managing the power supply system when the host PMU 12 fails to send the appropriate control signal.

To accomplish such tasks, especially such tasks dependent on use of two or more batteries (e.g., to avoid cross conduction between batteries), reference should be made to U.S. Patent Application Number 10/364,228 filed February 11, 2003, the teachings of which are incorporated herein by reference, which discloses a selector circuit that may be utilized as part of a power supply system consistent with the invention.

Turning to FIGs. 5 – 8, various additional embodiments of power supply systems consistent with the invention of FIGs. 1 and 2 are illustrated having a controllable adapter 104a and two batteries (Battery A and B). In general, the main difference between the embodiments of FIGs. 5 – 8 and that earlier detailed regarding FIG. 4 is in the number of sense resistors utilized along various power paths. Otherwise, the functionality of the embodiments is similar to that earlier described with reference to FIG. 4 except that the decision circuit may not receive as many input current signals if less sense resistors are utilized. The embodiment of FIG. 5 has an adapter sense resistor 4, a Battery A sense resistor 7, and a Battery B sense resistor 5. The embodiment of FIG. 6 has a system sense resistor 3, a Battery A sense resistor 7, and a Battery B sense resistor 5. The embodiment of FIG. 7 has an adapter sense resistor 4, and one battery sense resistor 5 sensing current flow along path 118. Finally, the embodiment of FIG. 8 has a system sense resistor 3 and one battery sense resistor 5 sensing current flow along path 118.

Turning to FIGs. 9 – 15, various additional embodiments of power supply systems consistent with the invention of FIGs. 1 and 3 are illustrated having a DC to DC converter 104b as the controllable DC power source 104, a fixed adapter 302, and two batteries (Battery A and B) as the battery source 105. In general, the main difference
5 between the embodiments of FIGs. 9 – 15 and that earlier detailed regarding FIGs. 1 and 3 is in the number and position of sense resistors utilized along various power paths.

The embodiment of FIG. 9 has a DC to DC converter sense resistor 4, a system sense resistor 3, a Battery A sense resistor 7, and a Battery B sense resistor 5. The embodiment of FIG. 10 has a DC to DC converter sense resistor 4, a Battery A sense
10 resistor 7, and a Battery B sense resistor 5. The embodiment of FIG. 11 has a system sense resistor 3, a Battery A sense resistor 7, and a Battery B sense resistor 5. The embodiment of FIG. 12 has an adapter sense resistor 4 and one battery sense resistor 5 sensing current flow along path 118. The embodiment of FIG. 13 has one system sense resistor 3 and one battery sense resistor 5 sensing current flow along path 118. The
15 embodiment of FIG. 14 has one DC to DC converter sense resistor 3 coupled in series along an output path of the DC to DC converter 104b, and one battery sense resistor 5. Finally, the embodiment of FIG. 15 has one adapter sense resistor 4 coupled to an output of the fixed adapter 302 and at an input to the DC to DC converter 104b, a Battery A sense resistor 7, and a Battery B sense resistor 5.

20 In certain instances, one or more batteries may be deeply discharged. That is, the output voltage level of the deeply discharged battery may be less than the minimum voltage level necessary for proper operation of the battery and/or the system. When

charging such a deeply discharged battery, a wake up battery charging current level may be provided to the battery. This wake up battery charging current level is typically relatively small compared to the normal charging current, e.g., about 10% of normal charging current level in one instance. A wake up battery charging voltage level may also be relatively small compared to the normal charging voltage level. When the output voltage level of the battery rises above a wakeup threshold level, normal charging current and voltage levels may then be delivered. Otherwise, degradation of the battery may result if a normal charging current is provided to a deeply discharged battery.

In some battery supply topologies, the battery and the system load may be supplied by different power sources thus enabling one power source, e.g., a DC to DC converter, to provide a deeply discharged battery with a reduced charging current and voltage level while enabling the other power source, e.g., an ACDC adapter, to supply relatively higher current and voltage levels to the system load. In a battery supply topology consistent with the embodiment of FIG. 1 having one power source (e.g., controllable DC power source 104) that may provide power to both the system load 110 and to the battery 105 for charging (as in supply mode 183 of table 180), it would be advantageous to have an alternative method for providing a wake up charging current to the battery 105 while supplying the system load 110 with voltage levels as necessary.

Turning to FIG. 16, another embodiment of an electronic device 1600 having a controllable DC power source 104 and Battery A that may, individually or together, provide power to the system load 110 is illustrated. FIG. 16 has similar components to

earlier detailed components of FIG. 1 that are labeled similarly and hence any repetitive description of such components is omitted herein for clarity. For clarity only one battery, Battery A and its associated selectively unidirectional switch SW2A is illustrated in the embodiment of FIG. 16. Of course, additional batteries and additional
5 associated selectively unidirectional switches in parallel with Battery A may also be utilized.

In the embodiment of FIG. 16, the selectively unidirectional switch SW2A for Battery A may be implemented utilizes switches SW2A1 and SW2A2 having diodes D1 and D2 in parallel with each respective switch. Each individual switch SW2A1 and
10 SW2A2 when closed may be bidirectional permitting current flow in both directions. However, when one of the switches SW2A1 and SW2A2 is open and the other is closed, the switch SW2A may function as a selectively unidirectional switch by allowing current to flow in one direction but blocking it in the opposite direction with the body diode, D1 or D2, in parallel with the open switch.

15 For instance, as detailed in table 1680, during a charging supply mode 183, switch SW2A1 may be ON and switch SW2A2 may be OFF. Therefore, charging current from the source 104 to Battery A is permitted to flow through closed switch SW2A1 and diode D2 in parallel with open switch SW2A2 to charge the battery. However, current flow in the reverse direction from Battery A to the system load 110 is prevented by
20 diode D2 in this charging supply mode 183.

Advantageously, the power management circuit 1630 may include a wake up circuit 1608. The wake up circuit 1608 may be responsive to various input and/or

command signals to provide a control signal to the selectively unidirectional switch SW2A along path 20. The control signal provided by the wake up circuit 1608 may be representative of a wake up charging condition or a normal charging condition. In response to a wake up charging condition signal, the selectively unidirectional switch SW2A may enable only a wake up charging current to flow towards Battery A. In response to a normal charging condition signal, the selectively unidirectional switch SW2A may enable normal charging current to flow towards Battery A.

Turning to FIG. 17, details of the power management control circuit 1630 and the wake up circuit 1608 of FIG. 16 are illustrated. For clarity, only switch SW2A1 of the selectively unidirectional switch SW2A of FIG. 16 is illustrated. The wake up circuit 1608 may include a comparison circuit 1718 and an output decision circuit 1612. The comparison circuit 1718 may include an error amplifier 1610. The error amplifier 1610 may receive an ICDA signal at its inverting input terminal representative of an instantaneous charging current level provided to Battery A when the system is in the charging supply mode 183 as detailed in table 1680. The ICDA signal may be provided by sense amplifier 17 via path 1706. Sense amplifier 17 may have its noninverting input coupled to terminal 1702 and its inverting input coupled to terminal 1704. Conductors may be coupled across Battery A sense resistor 7 and coupled to terminals 1702, 1704 to provide the input to the sense amplifier 17 representative of the charging current level provided to Battery A in a charging supply mode.

The error amplifier 1610 may also receive a signal at its noninverting input representative of a predetermined wake up current level. The predetermined wake up

current level may be a fixed or programmable current level to account for varying battery sizes, types, and charging conditions. Such a signal representative of the wake up current level may be provided by a variety of sources including a host PMU 12 via the PMU host interface 13. The error amplifier 1610 then compares the signal

5 representative of the instantaneous charging current level with the signal ICDA representative of the wake up current level and provides a comparison output signal to the output decision circuit 1612.

The output decision circuit 1612 of the wake up circuit 1608 receives a variety of input and/or command signals including the comparison output signal from the
10 comparison circuit 1718 and a selector signal from a selector circuit 409 as provided via path 1714. The output decision circuit 1612 may provide either the comparison output signal or the selector signal to a control terminal of the switch SW2A1 to control a conduction state of the switch SW2A1. The output decision circuit 1612 may comprise a variety of logic circuits known in the art to provide the desired functionality.

15 When the output decision circuit 1612 provides the comparison output signal from the comparison circuit 1718 to the switch SW2A1, the switch SW2A1 is responsive to this signal to limit the charging current level provided to Battery A to the wake up current level. In one embodiment, the switch SW2A1 may provide a constant current flow to Battery A equal to the wake up charging current level. The comparison output
20 signal may be an analog signal and the switch SW2A1 may be responsive to this analog signal to enter an intermediate conduction state. As used herein, an "intermediate conduction state" means a state that at least somewhat limits current flowing from one

terminal to another terminal of the switch. As such, the switch SW2A1 in an intermediate conduction state may limit current provided to battery A to a wake up current level when the battery A is deeply discharged. In one instance, the switch SW2A1 may behave like an error amplifier controlled resistor when it receives the comparison output signal from the comparison circuit 1718.

The switch SW2A1 may be any variety of transistors to receive any variety of analog signals. For instance, the switch may be a field effect transistor as illustrated having a gate terminal to receive a voltage analog signal from the output decision circuit 1612. The value of this voltage analog signal then controls the current flowing between the other two terminals or the source and drain terminals in this instance. The switch 1612 may also be as bipolar junction transistor having a base terminal to receive a current analog signal from the output decision circuit 1612. The value of this current analog signal then controls the current flowing between the other two terminals or the collector and emitter terminals in this instance.

When the output decision circuit 1612 provides the selector output signal, the switch SW2A1 is responsive to this signal to be either ON or OFF. The signal provided by the selector circuit may be a digital signal such that if the digital signal is a digital one, switch SW2A1 may be ON and if the digital signal is a digital zero, switch SW2A1 may be OFF. When switch SW2A1 is ON in response to the selector output signal, the switch SW2A1 may be in a full conduction state. As used herein, a "full conduction state" means a state that does not appreciably limit current flowing from one terminal to another terminal of the switch. Therefore, if switch SW2A1 is ON in response to the

selector output signal, normal charging current levels may then be provided to Battery A. Therefore, the comparison output signal, e.g., an analog signal in one embodiment, may be utilized to control switch SW2A1 when Battery A is deeply discharged and hence charging current may be limited to a wake up charging current level. In addition, the selector output signal, e.g., a digital signal in one embodiment, may be utilized to control switch SW2A1 and provide higher normal charging current levels to Battery A.

The output decision circuit 1612 may also accept additional input and/or command signals along bus 1614. Such signals may be provided by a host of sources including the host PMU 12 via the host interface 13, the power management control circuit 1630, or may also be set externally from the power management control circuit 1630. One such signal received along bus 1614 may be an enabling signal. If the enabling signal is in a first state, e.g., a digital one, the output decision circuit 1612 may be enabled to provide the comparison output signal from the comparison circuit 1718 to switch SW2A1. If the enabling signal is in a second state, e.g., a digital zero, the output decision circuit 1612 may then provide the selector output signal swA2 to the switch SW2A1.

Another signal that may be received by the output decision circuit 1612 via bus 1614 is a battery voltage signal representative of a maximum charging voltage during wake up charging. If this battery voltage signal indicates the voltage level of the battery during wake up charging exceeds a threshold voltage level, then the output decision circuit 1612 may stop wake up charging by providing the selector output signal to switch SW2A1 rather than the comparison output signal.

Yet another signal that may be received by the output decision circuit 1612 via bus 1614 is a maximum wake up charge time signal. If this signal indicates that the battery has been provided a wake up charging current for more than a maximum time interval, then the output decision circuit 1612 may stop wake up charging by providing the selector output signal to switch SW2A1. Other signals may also be provided to the output decision circuit 1612 to provide additional functionality.

In one embodiment, there is thus provided a wake up circuit comprising a comparison circuit adapted to receive a first signal representative of a charging current level provided to a battery via a path and a second signal representative of a predetermined wake up current level and to provide a comparison output signal in response to the first and second signal. The wake up circuit may also include an output decision circuit adapted to receive at least the comparison output signal and a selector signal from a selector circuit, the output decision circuit providing one of the comparison output signal and the selector signal to a switch to control a state of the switch, the switch coupled to the path.

In another embodiment, there is provided an apparatus comprising a wake up circuit consistent with the above detailed embodiment.

In yet another embodiment, there is provided an apparatus comprising: a first path configured to be coupled to a controllable DC power source; a second path configured to be coupled to a battery; a third path configured to be coupled to a system load, wherein the first, second, and third paths are coupled to a common node; a first switch coupled to the first path to allow selective coupling of the controllable DC power

source to the system load via the common node; a second switch coupled to the second path to allow selective coupling of the battery to the common node; and a wake up circuit comprising a comparison circuit and an output decision circuit. The comparison circuit may be adapted to receive a first signal representative of a charging current level
5 provided to the battery via the second path and a second signal representative of a predetermined wake up current level of the battery and to provide a comparison output signal in response to the first and second signal, the output decision circuit adapted to receive at least the comparison output signal and a selector signal from a selector circuit, the output decision circuit providing one of the comparison output signal and
10 the selector signal to the second switch to control a state of the second switch.

It will be appreciated that the functionality described for the embodiments of the power management control circuit and wake up circuit may also be implemented using software, or a combination of hardware and software. If implemented in software, a processor and machine-readable medium may be required. The processor can be any
15 type of processor capable of providing the speed and functionality required by the embodiments of the invention. For example, the processor could be a process from the Pentium® family of processors made by Intel Corporation, or the family of processors made by Motorola. Machine-readable media include any media capable of storing instructions adapted to be executed by a processor. Some examples of such media
20 include, but are not limited to, read-only memory (ROM), random-access memory (RAM), programmable ROM (PROM), erasable programmable ROM (EPROM), electronically erasable programmable ROM (EEPROM), dynamic RAM (DRAM),

magnetic disk (e.g. floppy disk and hard drive), optical disk (e.g. CD-ROM), and any other device that can store digital information. In one embodiment, the instructions may be stored on the medium in a compressed and/or encrypted format.

5 The embodiments that have been described herein, however, are but some of the several which utilize this invention and are set forth here by way of illustration but not of limitation. It is obvious that many other embodiments, which will be readily apparent to those skilled in the art, may be made without departing materially from the spirit and scope of the invention as defined in the appended claims.